NHTSA

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Comparison of Seat Belt Elongation Performance

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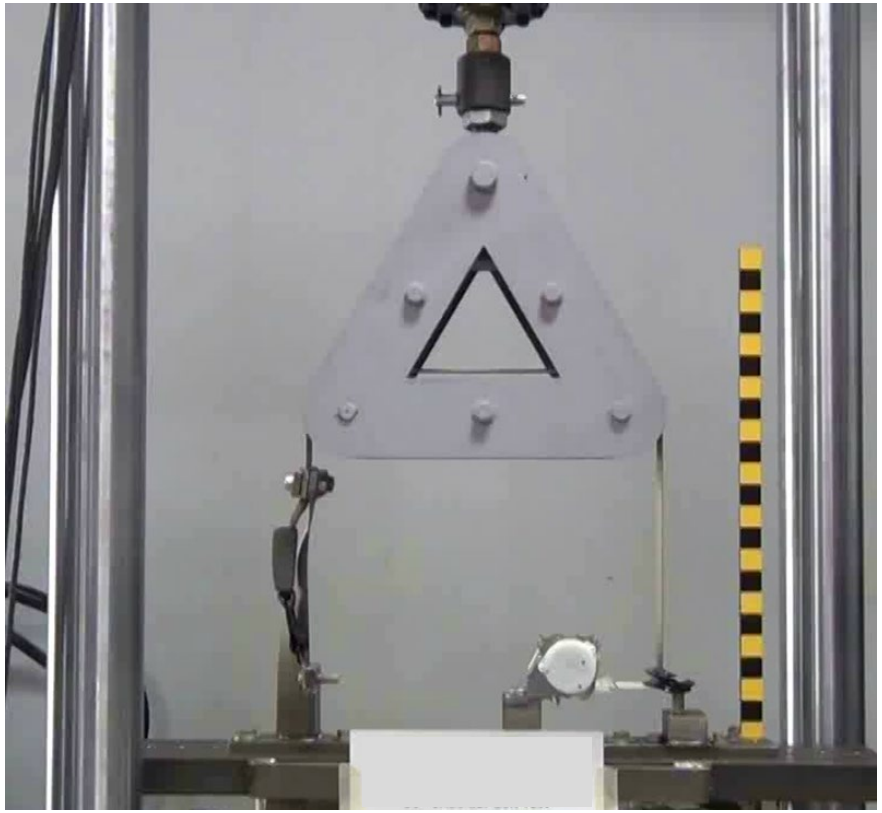
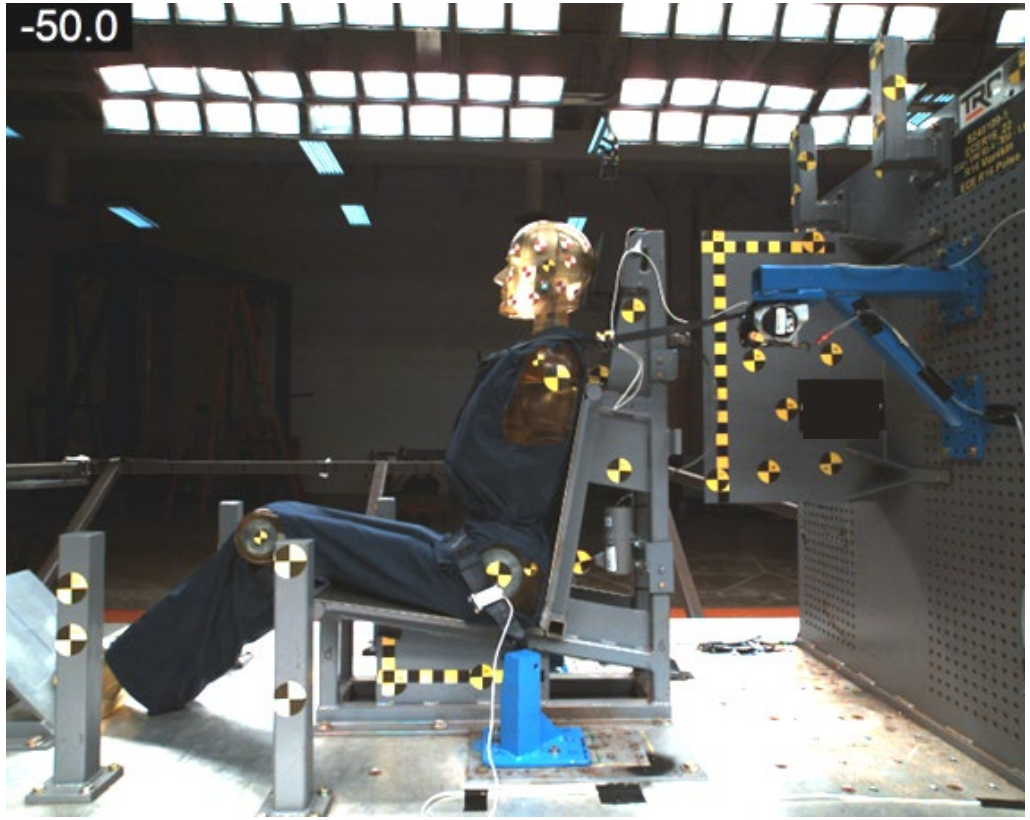
Background



§571.209 Standard No. 209; Seat belt assemblies.



Safety-Belts and Restraint Systems Regulation No. 16-05

LL = Load Limiter
RPT = Retractor Pretensioner

**No buckle or anchor PT tested

Test Matrix

YR/MAKE/MODEL	MARKET	LL	RPT	209 Tensile Test	R16 Dynamic Test	Rear Seat Sled Test
2019 Chevrolet Suburban	US	No	No	X	X	
2019 Chevrolet Suburban	EU	No	No	X	X	
2019 Lexus ES 350	US	Yes	Yes	X	X	X
2019 Lexus ES 350	EU	Yes	Yes	X	X	X
2018 Subaru Impreza	US	No	No	X	X	X
2018 Subaru Impreza	EU	Yes	Yes	X	X	X
2021 VW ID.4	US	Yes	Yes	X	X	X
2021 VW ID.4	EU	Yes	Yes	X	X	X
2023 Nissan Altima	US	Yes	Yes	X	X	
2023 Nissan Altima	CC	Yes	Yes	X	X	

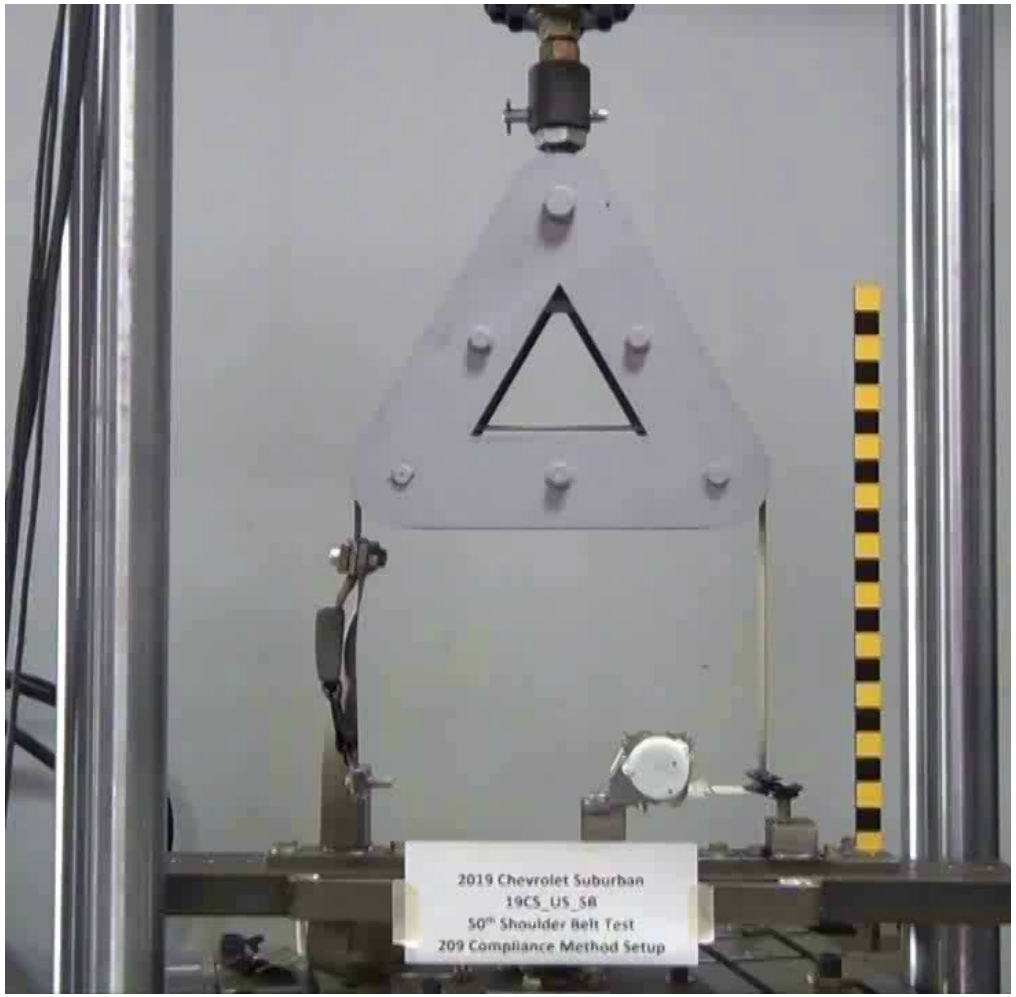
- Completed physical testing using 3 test methods (209, R16, rear seat sled)
  - R16 manikin, Hybrid-III 50, THOR-50M ATDs tested in R16 and rear seat sled conditions
- Comparisons between the test methods, seat belt assemblies/technologies, and performance/injury metrics

FMVSS No. 209 Tensile Test

- Completed tensile tests, both lap and shoulder belt set-ups, per FMVSS No. 209 test procedure

  Test Criteria

  - Lap belt force = 22,241 N
  - Shoulder belt force = 13,345 N
  - Elongation limit of 508 mm



FMVSS No. 209 Tensile Test - Results

Test Criteria

Lap belt force = 22,241 N

Elongation limit of 508 mm

Lap Belt Test	
Belt	**Elongation (mm)**
2019 Chevrolet Suburban (US)	158
2019 Chevrolet Suburban (EU)	151
2019 Lexus ES (US)	126
2019 Lexus ES (EU)	120
2018 Subaru Impreza (US)	194
2018 Subaru Impreza (EU)	196
2021 VW ID.4 (US)	161
2021 VW ID.4 (EU)	154
2023 Nissan Altima (US)	140
2023 Nissan Altima (CC)	134

Test Criteria

Shoulder belt force = 13,345 N

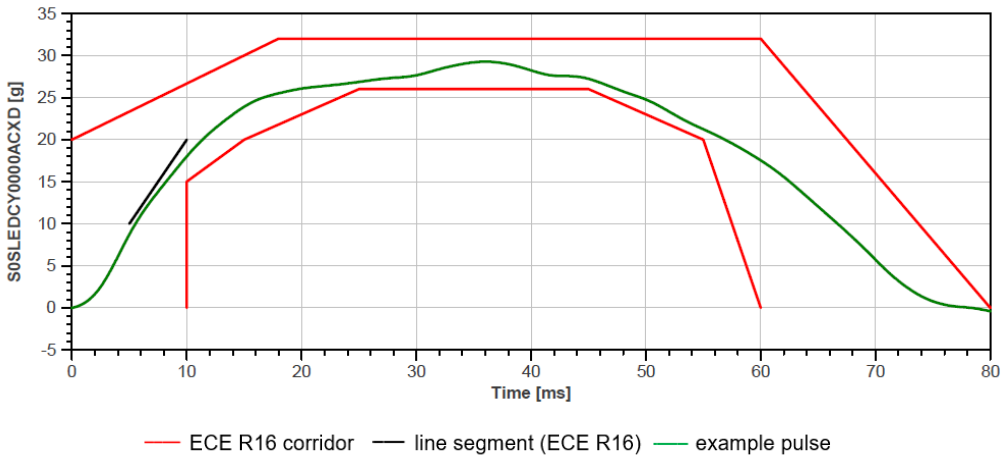
Elongation limit of 508 mm

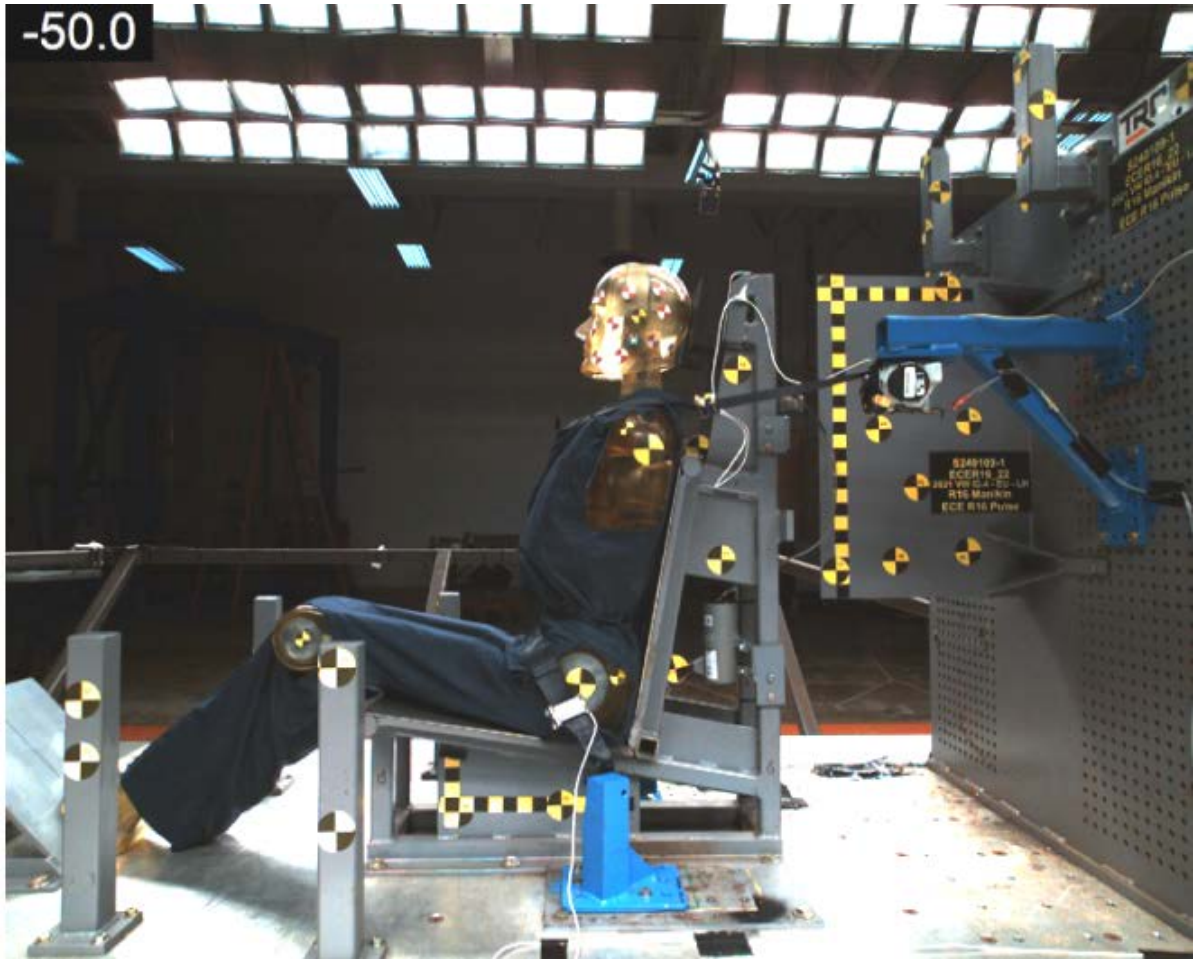
Shoulder Belt Test		
Belt	**LL?**	**Elongation (mm)**
2019 Chevrolet Suburban (US)	N	156
2019 Chevrolet Suburban (EU)	N	150
2019 Lexus ES (US)	Y	425
2019 Lexus ES (EU)	Y	960
2018 Subaru Impreza (US)	N	155
2018 Subaru Impreza (EU)	Y	1220
2021 VW ID.4 (US)	Y	462
2021 VW ID.4 (EU)	Y	358
2023 Nissan Altima (US)	Y	379
2023 Nissan Altima (CC)	Y	1245

LL = Load Limiter

UN ECE R16 Dynamic Test

- ECE R16 dynamic test
  - Used vehicle specific seat belt mounting locations provided by OEMs
  - Pulse corridor and ΔV = 51 +2/-0 km/h (31.7 +1.2/-0 mph)
- Forward displacement of manikin pelvis and torso measured using string potentiometers





UN ECE R16 Dynamic Test - Results

Belt	LL/PT?	String Potentiometer Result R16 Manikin	
		Pelvis	Torso
2019 Chevrolet Suburban (US)	N/N	150*	*
2019 Chevrolet Suburban (EU)	N/N	153	247
2019 Lexus ES (US)	Y/Y	97	282
2019 Lexus ES (EU)	Y/Y	99	310
2018 Subaru Impreza (US)	N/N	216	210
2018 Subaru Impreza (EU)	Y/Y	114	224
2021 VW ID.4 (US)	Y/Y	65	218
2021 VW ID.4 (EU)	Y/Y	67	303
2023 Nissan Altima (US)	Y/Y	72	248
2023 Nissan Altima (CC)	Y/Y	89	314

*D-ring sheared off during test

Test criteria

- No part of assembly or restraint system shall break, and no buckles or locking system shall release
- Forward displacement of manikin

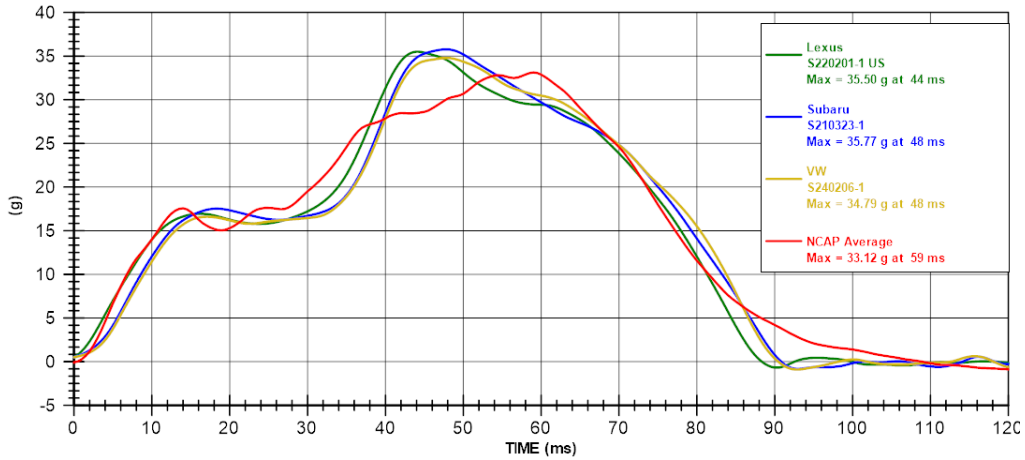
  Pelvis: (40) 80 – 200 mm

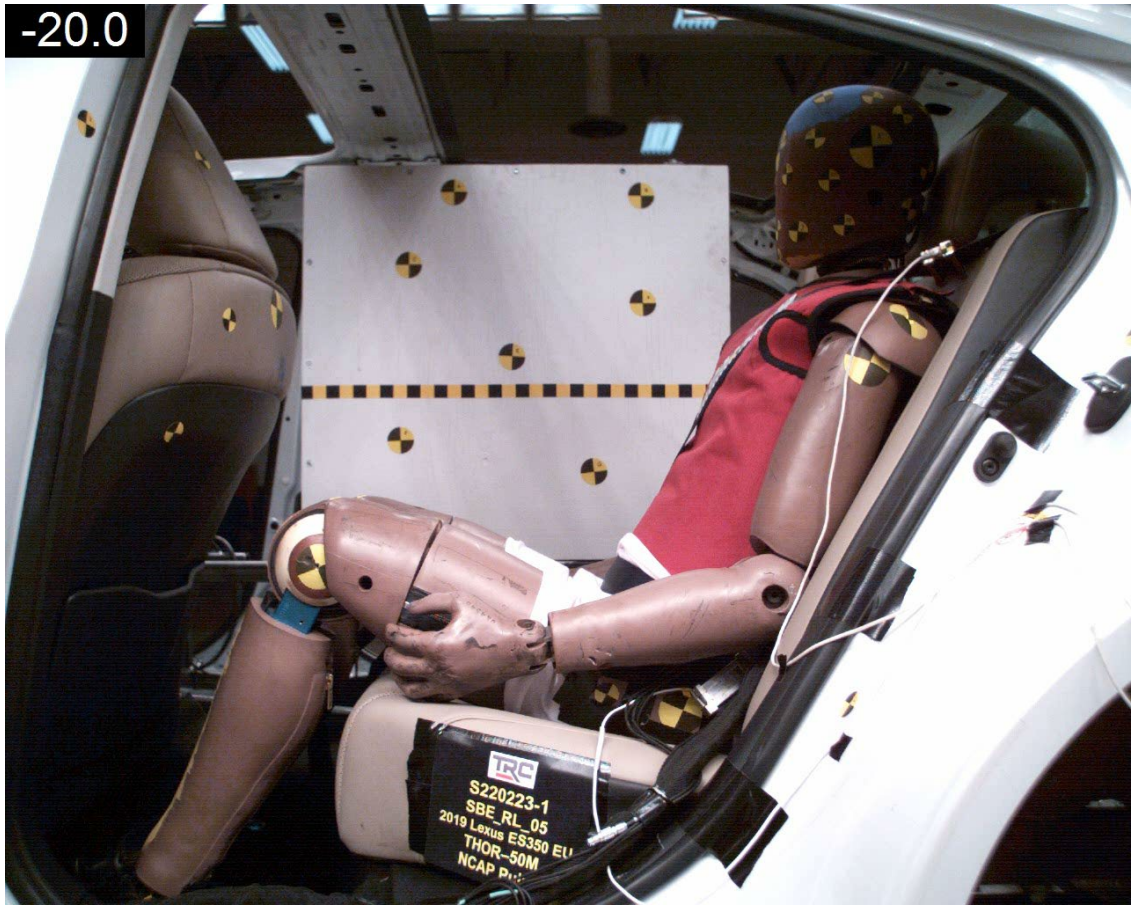
  Torso: (50) 100 – 300 mm

  * With PT the minimum displacement requirement is reduced to half its original value

Rear Seat Sled Test

- Selected 3 seat belt assembly matched pairs from previous tests
  - Lexus ES350, Subaru Impreza WGN, VW ID.4
- Fabricated rear seat sled bucks
- Conducted sled tests with R16 manikin, HIII-50th, THOR-50M
  - Target pulse = 33 g (actual: 35 g average)
  - Target velocity = 40 mph (64 km/h)
- Collected ATD injury metrics for HIII-50th and THOR-50M ATDs





Rear Seat Sled Test - Results

Injury Assessment Risk Value (IARV)			700[1]		0.96[2]		HIII: 1.0[1] THOR: 1.11[2]		60.0[1]		HIII: 63.0[1] THOR: 51.4[2]	
Seat Belt Assembly			**HIC 15**		**BrIC**		**NIJ Max**		**Chest Clip (3ms) (g)**		**Chest Deflection (mm)**	
			HIII-50th	**THOR-50M**	**HIII-50th**	**THOR-50M**	**HIII-50th**	**THOR-50M**	**HIII-50th**	**THOR-50M**	**HIII-50th**	**THOR-50M**
2019 Lexus ES350	US	PT/LL	916[!]	1154	0.99	0.90 (QD)	0.75	0.98	38.6	51.1	38.9	73.4
2019 Lexus ES350	EU	PT/LL	566[!]	971	1.02	0.97	0.70	0.84	39.1	47.2	37.7	67.6
2018 Subaru Impreza	US	-	1153	2370	1.34	1.15	1.00	1.51	56.4	69.0	54.0 (QD)	71.4
2018 Subaru Impreza	EU	PT/LL	440[!]	557[!]	0.93	0.84	0.79	0.77	40.3	43.1	35.2	54.0
2021 VW ID.4	US	PT/LL	470	709	0.94	0.94	0.62	0.90	42.0	51.0	53.4	61.9
2021 VW ID.4	EU	PT/LL	914	864	1.18	1.15	0.82	1.01	39.1	61.3	59.8	66.3

[!] head contact with front seat back

Red: exceeds IARV
Yellow: 80% IARV

[1] Occupant crash protection injury criteria listed in TP208-14
[2] THOR-50M Injury Criteria Report (NHTSA-2019-0106-0008), 50% risk of AIS 3+

Comparisons/Summary

Of five matched pair comparisons:

- Two had performance in FMVSS 209 = ECE R16
- Three had performance in FMVSS 209 ≠ ECE R16

Of three matched pair comparisons with rear seat sled test data:

- Two had performance in FMVSS 209 and ECE R16 not indicative of occupant protection performance
- One had performance in the only ECE R16 test indicative of occupant protection performance

Of the seven seat belt assemblies with load limiters:

- Three met both the FMVSS 209 elongation and ECE R16 requirements
- Two met neither requirement
- One met only FMVSS 209, and one met only ECE R16

No clear trend from physical testing

FE Modeling

Generate supplemental data using FE modeling

1. Create and validate FMVSS 209 tensile test and ECE R16 dynamic test model environments
2. Conduct parametric study

Selected Nissan Altima US belt system for baseline

- ~3.3kN LL, PT, stopper, DLT

Validation Steps:

1. Completed component tests
2. Applied material properties and boundary conditions
3. Used same properties from tensile test for belt properties in R16 model

Component Tests

Webbing Elongation

- Method: Per FMVSS No. 209, S5.1(c)
- Output: webbing elongation % and loading/unloading curves

Retractor Pay-out

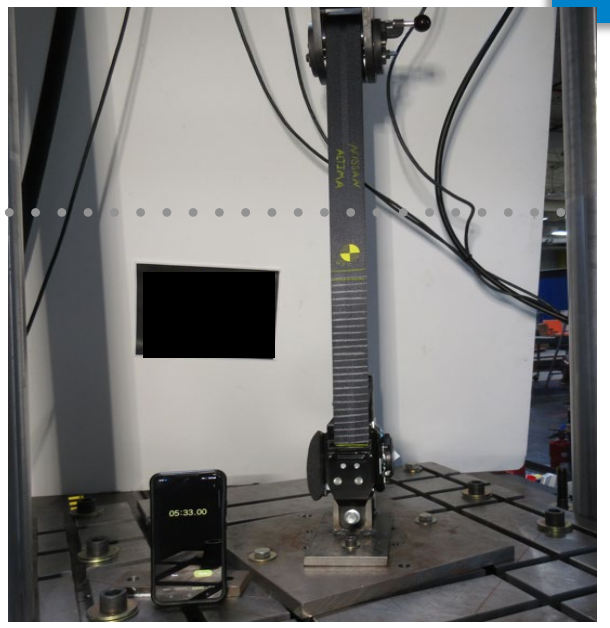
- Method: FMVSS No. 209 loop load test, but only used retractor not full assembly
- Output: retractor F-D curve

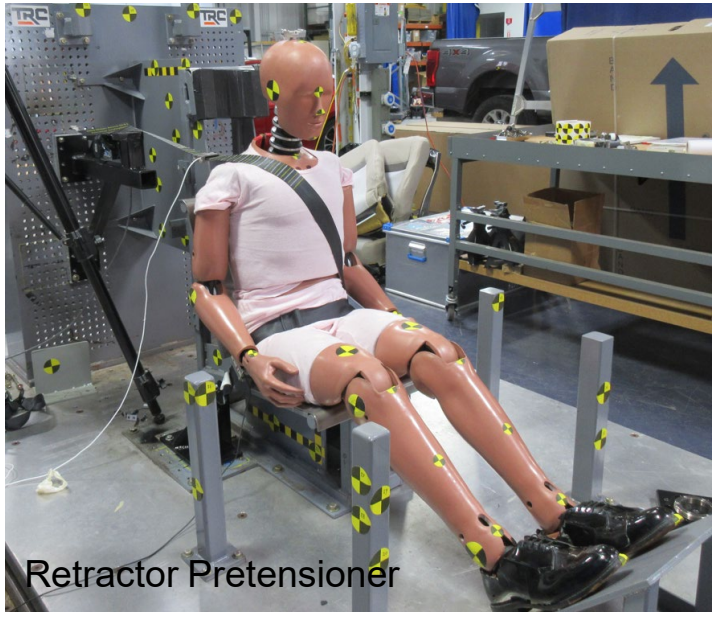
Retractor Pretensioner

- Method: Static deployment of retractor pretensioner with HIII-50th positioned on R16 bench
- Output: belt loads, belt displacement pay-in

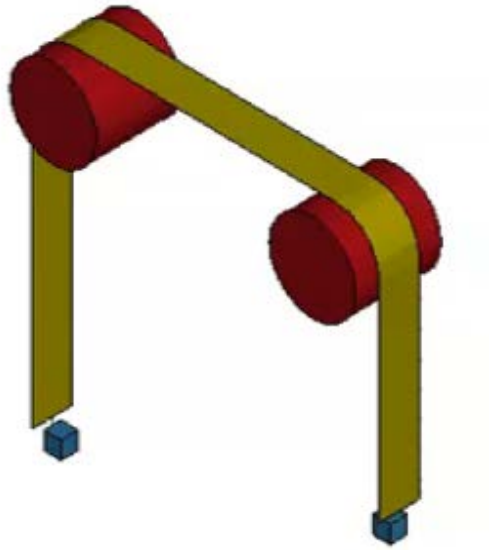


Webbing Elongation


Retractor Pay-out


Retractor Pretensioner

209 Model Validation

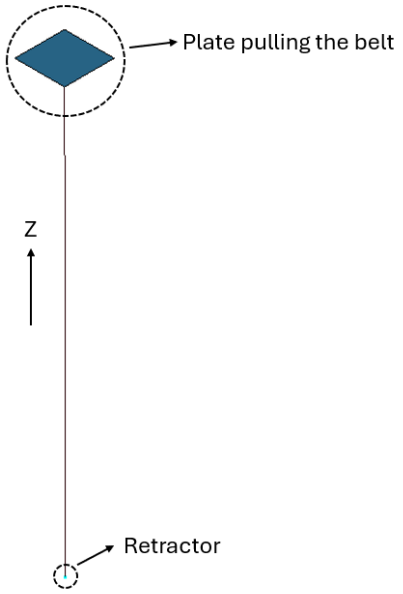


Started with model that matched physical test setup

- Due to simulation run time model was simplified to only one side (retractor)
- Lap belt setup was not modeled

Simplified model

- Single 2D plate with retractor modeled as a single node fixed in space
- Two assumptions:
  1. Left and right belt segment forces in the full setup are equal and half of MTS-measured force
  2. Left and right belt segment displacement in the full setup are equal and same as the MTS displacement
- Inputs from webbing elongation and retractor payout component tests
- Outputs of force and displacement
  - Belt elongation (2*displacement)



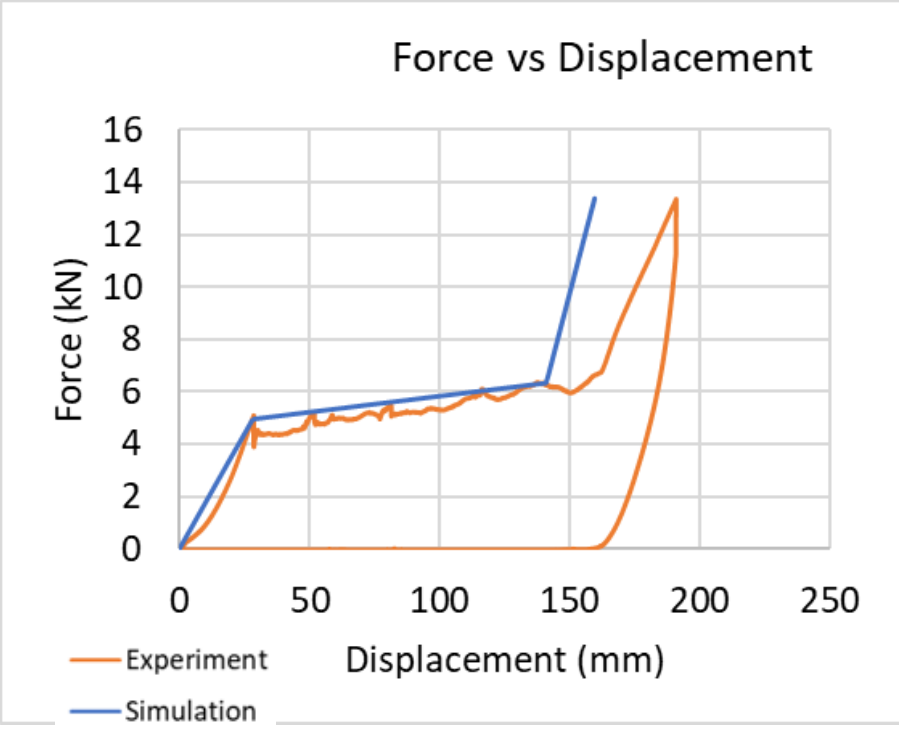
209 Shoulder Belt Model Validation

Nissan Altima US
(~3.3kN, PT, stopper, DLT)

Results of simulation were compared with physical test data

- Elongation = displacement x 2
- Elongation: experiment 379 mm vs simulation 320 mm

Differences in elongation between simulation and experiment likely due to anchor deformation which was not modeled in simulation





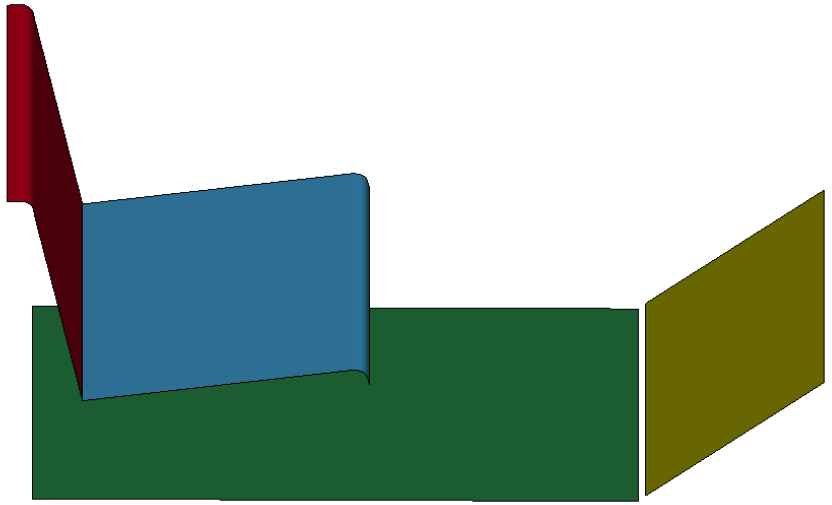
Pre-test

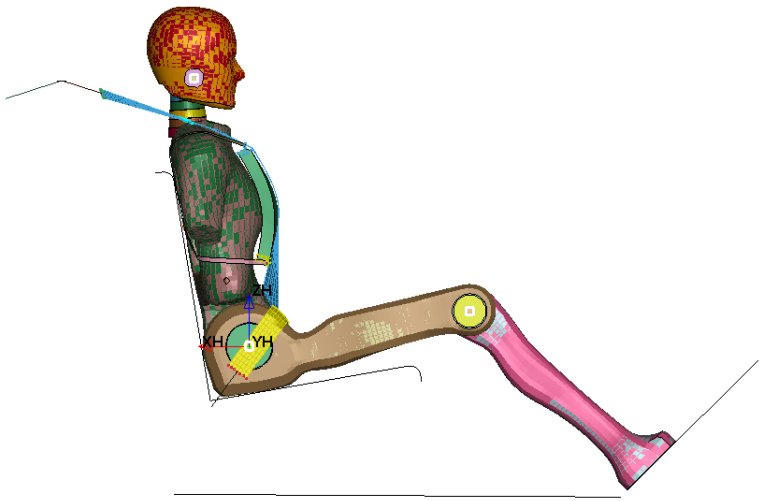


Post-test

R16 Model Validation

- Seat and anchor locations developed using FARO data from physical bench measurements
- Used qualified TNO-10 R16 manikin model
- Boundary Conditions
  - Belt guide loop friction coeff = 0.2
  - Buckle DLT friction coeff = 0.6
  - Fixed anchor mount locations
  - Buckle movement and deformation of anchors incorporated
- Inputs
  - Webbing loading and unloading curve
  - F-D input from retractor test
  - Pretensioner pay in curve
    - Pretensioner max force level monitored/controlled
- Outputs
  - Shoulder and lap belt forces
  - ATD displacement – chest and pelvis
  - Monitor peak head excursion





R16 Model Validation

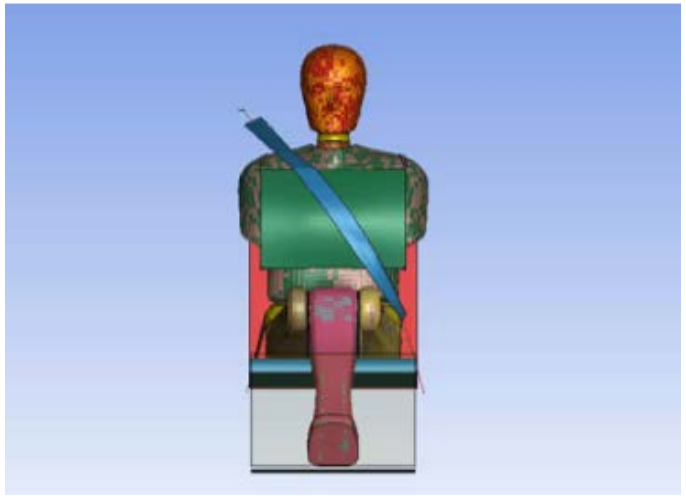
Experiment

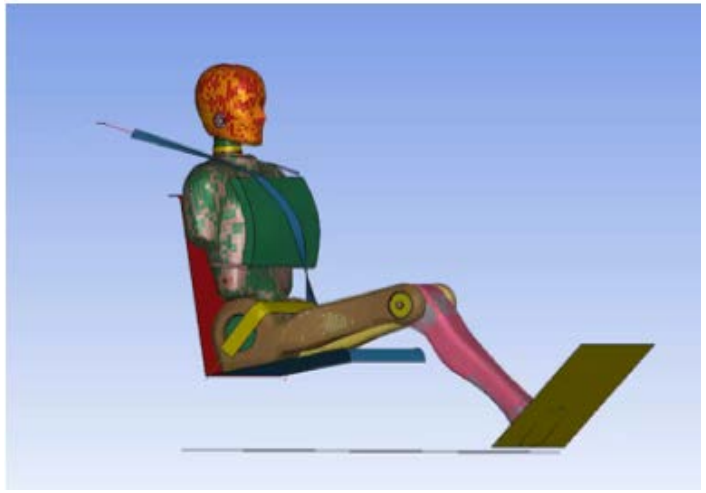


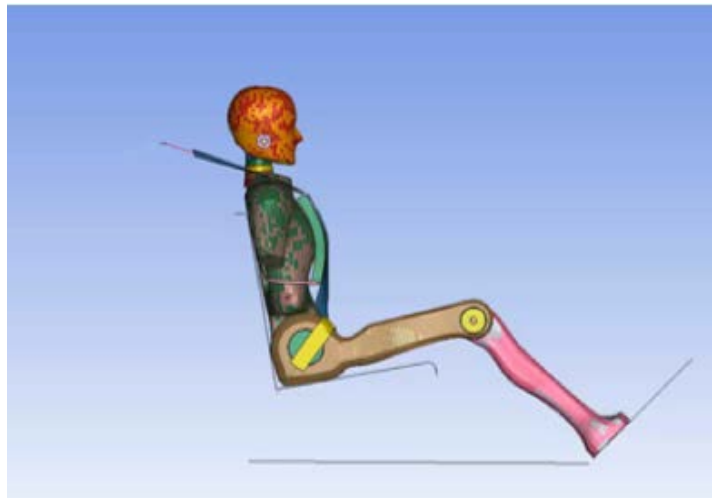




Simulation







R16 Model Validation

Nissan Altima US
(~3.3kN, PT, stopper, DLT)

Chest and pelvis excursions

- Peaks within 10% in magnitude

Lap belt force

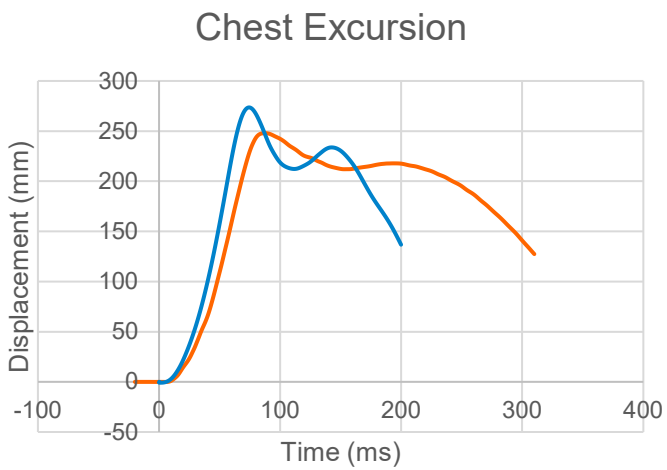
- Almost perfect overlap

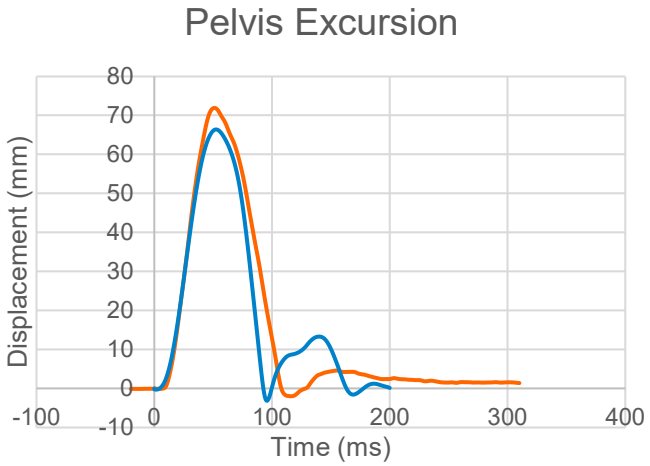
Shoulder belt force

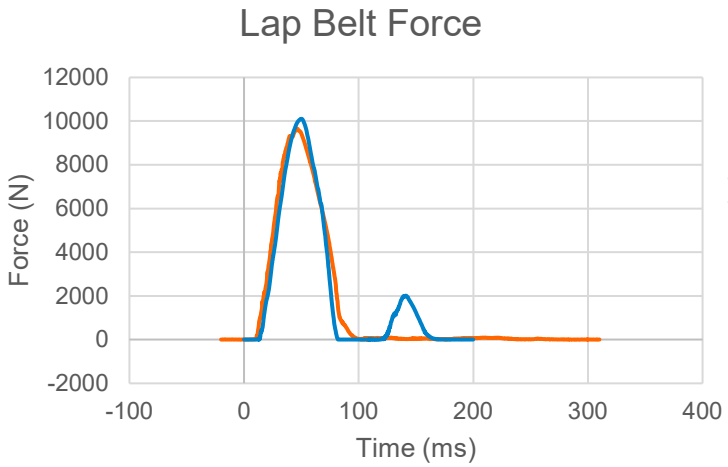
- Different shape and magnitude
- Similar initial pretension phase
- Experiment data had peak early from unknown event
- Simulation data followed input from retractor component test

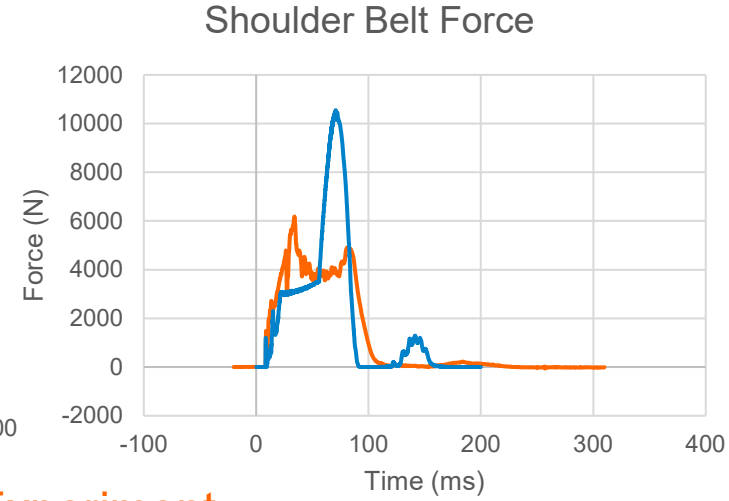
Second peak

- Different unloading between experiment and simulation – peak likely due to seatbelt contact from rebound









Experiment
Simulation

Parametric Study

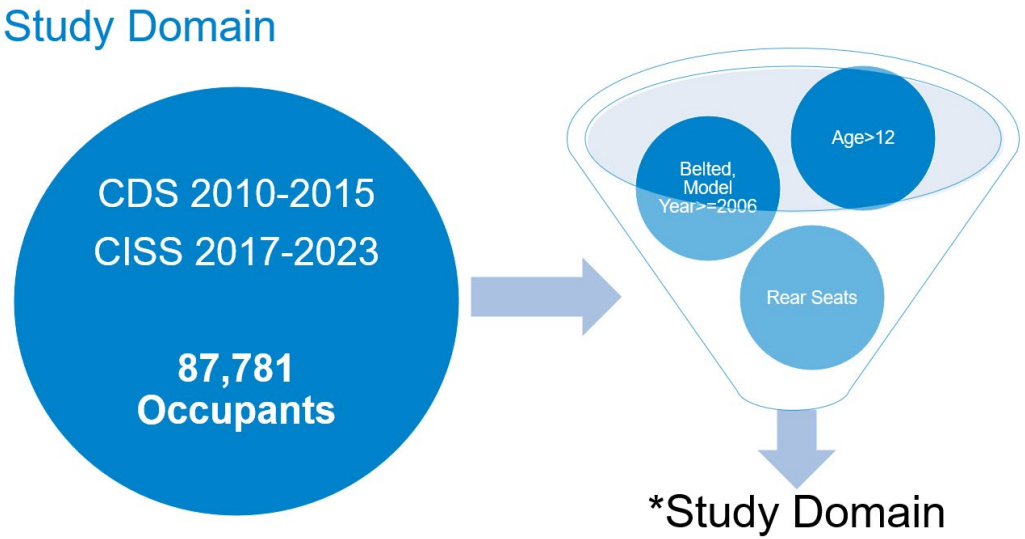
Parameter	Values simulated
LL Level	no LL, 2, 3, 4, 5, 6 kN
PT force level	no PT, 1kN, 1.5kN, 2kN, 2.5kN
PT duration	0 – 5 ms
PT firing	0, 2, 4, 6 ms
Stopper engagement	150, 200, 250, 300, 500 mm
DLT	N or Y
Anchor deformation	10, 20, 30, 40, 50 mm
Anchor locations	At limits of 50mm tolerance
Pulse	High, low

*Only retractor LL and PT

- Understand how parameters change seat belt response in relation to R16 and 209 elongation test requirements.
- Use the Nissan Altima US belt as the baseline
- Parameter values determined from literature and testing experience
- Run simulations varying parameters in both 209 and R16 condition
- Compare effect of parameters on performance in 209 and R16

Field Data

- Understand if allowing load limiters (LL) would enhance rear seat occupant protection
- Used NCAP data to match LL and PT with cases from CDS/CISS
- Three approaches – simple odds ratio, multivariate logistic modeling, matched modeling
- Low number of cases with rear seat belted occupants (~665 cases), with many missing information



Example NCAP data

MAKE	MODEL	MODEL_YR	SEAT_BELT_PRETENSIONER	SEAT_BELT_PRETENSIONER_LOC	LOAD_LIMITERS	LOAD_LIMITERS_LOC
FORD	BRONCO	2024	Standard	1,3,4,6	Standard	1,3,4,6
FORD	BRONCO	2024	Standard	1,3,4,6	Standard	1,3,4,6
FORD	BRONCO SPORT	2024	Standard	1,3,4,6	Standard	1,3,4,6
FORD	EDGE	2024	Standard	1,3,4,6	Standard	1,3,4,6
FORD	EDGE	2024	Standard	1,3,4,6	Standard	1,3,4,6
FORD	ESCAPE GAS	2024	Standard	1,3,4,6	Standard	1,3,4,6
FORD	ESCAPE GAS	2024	Standard	1,3,4,6	Standard	1,3,4,6
FORD	ESCAPE HEV	2024	Standard	1,3,4,6	Standard	1,3,4,6
FORD	ESCAPE HEV	2024	Standard	1,3,4,6	Standard	1,3,4,6
FORD	ESCAPE PHEV	2024	Standard	1,3,4,6	Standard	1,3,4,6

Summary & Next Steps

Physical Testing

- Data collected for 5 matched pair belts in 209 tensile and R16 dynamic tests
- Additional data from 3 matched pair belts in rear seat sled test
- No clear trends identified

FE Modeling

- 209 tensile and ECE R16 dynamic test setups validated
- Next steps: complete parametric study and analysis

Field Data

- Low number of cases of rear seated occupants with LL
- Next steps: Modify inclusion criteria to increase case counts, rerun models

NHTSA

Thank you for your attention.

Questions?

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